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(54) **Monitoring unit and method**

(57) A monitoring unit for determining the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the unit comprising inputs for receiving first data related to engine rotation, storage means (58) for storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition, and processing means (56) configured: i) to compare said received first data to said second data in order to determine a best matching template, and ii) to determine the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

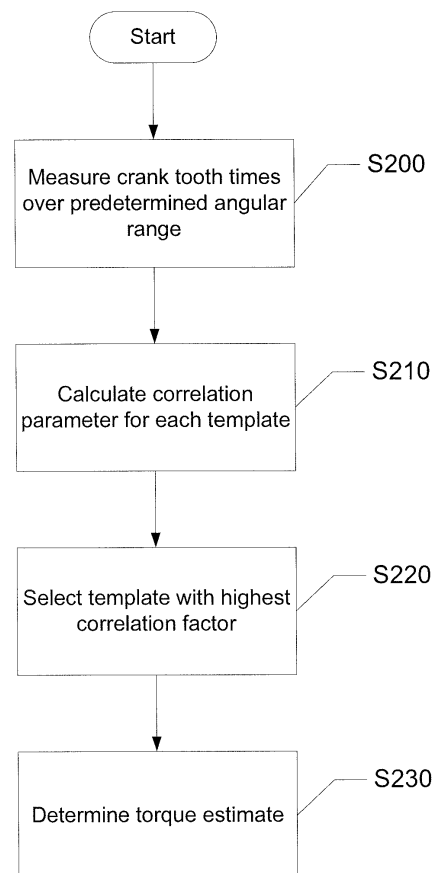


Fig. 6

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DescriptionField of the invention

[0001] The present invention relates to a monitoring unit for determining the operational condition of an engine, a method of monitoring the operational condition of an engine, a method of generating templates for use in an engine monitoring unit, and to a system for generating templates for use in an engine monitoring unit.

Background of the invention

[0002] The torque output of an internal combustion engine is a useful parameter which can be used for engine diagnostics, calibration and safety checks. Knowledge of the torque output can also be used as a proxy measure for the fuel delivered and cylinder pressure, on the basis that a given amount of fuel combusted under a given cylinder pressure should result in predictable torque output. Furthermore, a measured torque output can be compared to the expected torque output and used to determine injector or Engine Control Unit (ECU) errors.

[0003] However, there is a problem that conventional torque sensors which are suitable for measuring the torque output of the engine on a vehicle, i.e. dynamometers, are expensive. Accordingly, the inclusion of such conventional torque sensors on vehicles is not economical.

[0004] A known technique for indirectly measuring the torque output of an engine involves measuring the engine speed. Engine speed is not a constant, but follows an approximately sinusoidal pattern throughout successive combustion cycles. This is due to the effective spring-mass-damper system of a piston, con-rod, crankshaft and flywheel. The greater the torque, the higher the force on the piston and the larger the amplitude of the sinusoidal waveform observed. By using the spring-mass-damper model of an engine and fitting a measured engine speed to the parameters of the solution to the equation, an estimate of the engine torque can be derived.

[0005] However, such conventional modelling techniques are complex. Furthermore, in practice, a real engine speed measurement is noisy and does not follow the pattern predicted by the theoretical model. Accordingly, the accuracy of the torque determined by such techniques is limited.

[0006] It is therefore an object of the present invention to provide a torque estimating apparatus/method which substantially overcome or mitigate the problems with the conventional torque measurement techniques described above.

Summary of invention

[0007] According to a first aspect of the present invention, there is provided a monitoring unit for determining the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the unit comprising:

inputs for receiving first data related to engine rotation;
 storage means for storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition; and
 processing means configured: i) to compare said received first data to said second data in order to determine a best matching template, and ii) to determine the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

[0008] Thus, the present invention provides a monitoring unit which can determine the operational characteristic of an engine, such as the torque output of the engine or whether the engine has a fault without the use of a complex mathematical model of engine behaviour or a torque sensor, such as an engine dynamometer.

[0009] Preferably, said one or more engine parameters includes an engine torque output value, and determining the operational condition of the engine comprises determining the torque output of the engine in dependence on the engine torque output value associated with said best matching template.

[0010] Preferably, said one or more engine parameters includes an average engine speed.

[0011] Preferably, said one or more engine parameters includes fault identification information, and said processing means is arranged to determine the operational condition of the engine by determining if an engine fault has occurred in dependence on fault identification information associated with said best matching template. More preferably, said fault identification information comprises one of:

an indication of an engine cylinder misfire; and
 an indication of a fuel injector needle stuck open condition.

[0012] Preferably, the first and second data related to engine rotation comprises data relating to the rotation of a crank wheel within the engine. More preferably, the crank wheel comprises a group of regularly spaced crank teeth associated with each cylinder within the engine and the processing means is arranged to monitor the time taken for a given crank tooth to move past a crank tooth sensor and to subsequently determine the speed of the crank wheel. Still more preferably,

[0013] Conveniently, said first and second data related to engine rotation may comprise crank tooth times for one group of crank teeth associated with a particular engine cylinder. Alternatively, said first and second data related to engine rotation may comprise crank tooth times for each crank tooth on the crank wheel.

[0014] Conveniently, said processing means is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} crk_j \times temp_{ij}$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and

wherein the processing means is arranged to determine said best matching template by selecting the template having the highest calculated correlation factor.

[0015] Alternatively, said processing means is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} (crk_j - temp_{ij})^2$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and

wherein the processing means is arranged to determine said best matching template by selecting the template having the lowest calculated correlation factor.

[0016] Said processing means may be arranged to calculate a normalised correlation factor for each of said plurality of templates by dividing said correlation factor by the following expression;

$$\sum_{j=1:N} (crk_j^2 + temp_{ij}^2)$$

[0017] Conveniently, said processing means is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} [\max(crk_j) - \min(crk_j)] - [\max(temp_j) - \min(temp_j)]_i$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and

wherein the processing means is arranged to determine said best matching template by selecting the template having the lowest calculated correlation factor.

[0018] According to a second aspect of the present invention, there is provided a method of monitoring the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the method comprising:

receiving first data related to engine rotation;

storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition;

comparing said first data to said second data;

determining a best matching template in dependence on the result of said comparing step; and

determining the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

[0019] Preferably, a data carrier comprising a computer program arranged to configure a torque estimating unit or an engine control unit to implement the method according to the second aspect of the invention is provided.

[0020] According to a third aspect of the present invention, there is provided a method of generating templates for use in an engine monitoring unit, the method comprising;

operating an engine in accordance with a particular operational condition;

receiving data related to engine rotation; and

storing said data related to engine rotation in association with one or more engine parameters associated with said operational condition.

[0021] Preferably, said one or more engine parameters comprises an engine torque output value.

[0022] According to a fourth aspect of the present invention, there is provided a system for generating templates for use in an engine monitoring unit, the system comprising:

an engine operable in accordance with a particular operational condition;

an engine speed sensor for outputting data related to engine rotation;

storage means; and

processing means arranged to receive said data related to engine rotation and to store said data in said storage means in association with one or more engine parameters associated with said operational condition.

[0023] Preferably, the system comprises an engine torque output sensor, wherein one or more engine parameters comprises an engine torque output value.

[0024] Preferred and/or optional features of the first aspect of the invention may be incorporated within any one of the method of the first aspect, the method of the second aspect, the method of the third aspect or the system of the fourth aspect, alone or in appropriate combination.

Brief description of the drawings

[0025] Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 illustrates the typical disposition of pickup teeth on a flywheel of an engine;

Figure 2 illustrates the output of a sensor monitoring the rotation of the flywheel of Figure 1 and shows the time between successive crank teeth on the flywheel;

Figure 3 is a schematic view of apparatus for generating templates for use in a torque estimating device in accordance with an embodiment of the present invention;

Figure 4 is a flow diagram showing the process of obtaining a template using the apparatus of Figure 3;

Figure 5 is a schematic view of a torque estimating device in accordance with an embodiment of the present invention; and

Figure 6 is a flow diagram showing the process of obtaining a torque estimate using the device of Figure 5.

Detailed description of the preferred embodiments

[0026] In a compression-ignition internal combustion engine, such as a diesel engine, combustion takes place within one or more combustion chambers or cylinders, each chamber being defined partly by a reciprocating piston and partly

by the walls of a cylinder bore formed in a cylinder head. The piston slides within the cylinder so that, when the engine is running, the volume of the combustion chamber cyclically increases and decreases. When the combustion chamber is at its minimum volume, the piston is said to be at 'top dead centre' (TDC), and when the combustion chamber is at its maximum volume, the piston is said to be at 'bottom dead centre' (BDC).

[0027] The piston is connected to a cranked portion of a crankshaft by way of a connecting rod and a flywheel (or crank wheel) is mounted on one end of the crankshaft. The reciprocating motion of the piston therefore corresponds to rotary motion of the crankshaft, and it is customary in the art to define the position of the piston according to the angle of the cranked portion of the crankshaft, with TDC corresponding to a crank angle of zero degrees. During a complete internal combustion cycle, comprising intake, compression, power and exhaust strokes of the piston, the crankshaft undergoes two whole revolutions, corresponding to a crank angle movement of 720°.

[0028] Figure 1 illustrates a typical flywheel 2. It can be seen that the flywheel 2 comprises a number of teeth 4 on its outer periphery which are arranged in three groups 6, 8, 10. Each group 6, 8, 10 is associated with an injector (injector X, injector X+1 and injector X+2 respectively) and each group comprises 18 teeth which are regularly spaced at 6-degree intervals. In Figure 2, the group of teeth associated with injector X are partially numbered (teeth 1, 11 and 18 are numbered).

[0029] Three regions 12, 14, 16 on the flywheel are not machined, i.e. have no teeth.

[0030] The sensor 18, which may be a variable reluctance sensor, is shown opposite tooth 11 in group 6. The sensor 18 is used to detect motion of the crank teeth 4 and the decoded signal output from the sensor 18 is used to provide position information which is used for engine speed measurement. It will be appreciated by those skilled in the art that any suitable sensor may be used to measure crank tooth motion, e.g. an optical based sensor may be used.

[0031] The crank tooth time is the time between successive crank teeth. This is illustrated in Figure 2 which shows the decoded signal output from the sensor of Figure 1. The time between tooth N and tooth N+1 is dt_N :

$$dt_N = T_Tooth_{N+1} - T_Tooth_N$$

where T_Tooth_N refers to the absolute time for tooth N.

[0032] Referring to Figure 3, an apparatus 30 for generating templates for use in a torque estimating device in accordance with an embodiment of the present invention comprises a test engine 32, an engine speed sensor 18, a torque sensor 34, a processor 36 and storage means 38.

[0033] The test engine 32 is an engine having the same specification as that with which the generated templates will be used to make torque estimates. The engine speed sensor 18 is of the kind described above with reference to Figures 1 and 2. Accordingly, the engine speed sensor 18 outputs a signal comprising information relating to the rotational speed of the test engine crankshaft when the engine is running. The torque sensor 34 is a conventional engine dynamometer and is coupled to the test engine 32. Accordingly, the torque sensor 34 outputs a signal relating to the torque output of the engine when running.

[0034] The processor 36 is coupled to and receives the respective signals output from the engine speed sensor 18 and the torque sensor 34. The processor 36 is further coupled to a storage means 38. The storage means 38 may be any suitable memory device, such as a hard disk drive, a flash memory, an optical disk etc.

[0035] The process by which templates are generated using the apparatus of Figure 3 will now be described with reference to Figure 4. In step S100, the test engine 32 is operated at a constant average engine speed. The test engine 32 is also controlled so as to operate at a constant torque output. Accordingly, in step S110, the torque output of the test engine is determined by the processor in dependence on the signal output from the torque sensor 34. For example, the test engine may be driven at an average speed of 1000rpm and produce a torque output of 40Nm. For a particular value of the torque output at a particular average engine speed, the engine speed sensor 18 outputs a series of measurements of the instantaneous engine speed, i.e. the crank tooth times, in step S120. In step S130, the processor 36 stores the measured engine speed data in the storage means 38 in association with the torque value determined by the torque sensor 34, thereby defining a template.

[0036] The above-described process may then be repeated for different values of average engine speed and torque output in order to generate a library of templates for the test engine 32. For example, as described above, a first template may comprise crank tooth times recorded at a torque output of 40Nm and average engine speed of 1000rpm. Further templates may be generated for different torque outputs at the same average engine speeds. Subsequently, the average engine speed may be incremented and the whole process may be repeated, thereby generating templates for a range of torque values and average engine speeds. In this way it is possible to build up a library of templates which cover the operational range of the engine.

[0037] A template may consist of crank tooth times measured over one injection cycle, i.e. corresponding to a 120° rotation of the crankshaft of a 6 cylinder engine. In this case a template would consist of the crank tooth times for each

of the eighteen crank teeth associated with a single injector.

[0038] Alternatively, measurements may be made over 2 revolutions of the crankshaft, i.e. a 720° rotation, in which case the measured torque output corresponds to an average torque output for all six engine cylinders.

[0039] Referring to Figure 5, the torque estimating unit 50 for estimating the torque output of an engine 52 comprises an engine speed sensor 18, a processor 56 and a memory 58. Typically, the processor 56 is the Engine Control Unit (ECU) of the vehicle in which the engine 50 is installed. As described previously, the engine speed sensor 18 outputs a signal to the ECU 56, which is used to determine the crank tooth times over the desired angular range of motion. The memory 58, which may be formed integrally with the ECU, stores a copy of the library of templates generated using the apparatus shown in Figure 3.

[0040] Referring to Figure 6, the process of obtaining a torque estimate using the torque estimating unit of the present invention will now be described.

[0041] In step S200, measurements of the crank tooth times are made over a predetermined angular range. More specifically, during running of the engine 52, the ECU 56 records the instantaneous engine speed for either 120 degrees or 2 revolutions, in dependence on the angular range over which the template data was collected using the test apparatus 30.

[0042] In step S210, a correlation measure between the measured engine speed data and each of the templates stored in the memory 58 is calculated using equation (1) shown below.

$$C_i = \sum_{j=1:N} crk_j \times temp_{ij} \quad (1)$$

where j indicates the index of the instantaneous engine speed and i indicates the template number. Thus, in the case that the angular range over which the measurements are taken is 120 degrees j will have a value of 18, since each template will comprise eighteen crank tooth times, $temp$, corresponding respectively to each of the crank teeth associated with a single injector. Similarly, there will be eighteen crank tooth measurements, crk , to compare to each of the eighteen $temp$ values in each template.

[0043] Referring to equation (1), the closer the match between the measured crank tooth times and the crank tooth times of a particular template, the greater the value of the correlation measure C .

[0044] In step S220, the calculated correlation measures for each template are compared. The template with the highest value of the correlation measure C , is selected for use in the determination of the torque output of the engine 52.

[0045] In step S230, an estimate of the torque output of the engine 52 is determined using the template selected in step S220. In one embodiment of the invention, the estimate of the torque output is equal to the measured torque value associated with the closest matching template. However, the actual torque will more usually be between the points at which the templates were measured. In this case the torque estimate can be found from a weighted sum of the torques of the best matching template and its most closely matching neighbour.

[0046] Using templates recorded over 2 engine revolutions permits the mean torque per cylinder to be estimated. Using templates recorded over individual injection cycles however enables the torque for each individual cylinder to be measured. Thus variations in cylinder to cylinder torque, and variation over time can be determined.

[0047] The greater the number of templates used for comparison in step S210, the greater the precision with which the torque output of the engine 52 can be estimated. However, as the number of templates used for comparison increases, so the load on the ECU 56 increases, as does the memory space required to store the templates and the time required to obtain the templates using the test cell. Accordingly, the number of templates used may be selected so as to achieve the optimum balance between the precision required and the constraints imposed by the processor speed, memory size and available calibration time.

[0048] As described above, each template comprises a series of measurements of instantaneous engine speed (i.e. crank tooth times), measured at a particular average engine speed and at a particular measured torque output. The templates may be scaled to interpolate between the particular values of average engine speed.

[0049] By means of the method described with reference to Figure 6, the torque output of an engine can be estimated without the need for an individual dynamometer to be connected to the engine. The estimated torque output can be used in a number of ways, e.g. diagnostics, calibration and safety checks.

[0050] In an alternative embodiment of the present invention, the correlation measure calculated in step S210 may be determined as a square of differences using equation (2) shown below;

$$C_i = \sum_{j=1:N} (crk_j - temp_{ij})^2 \quad (2)$$

[0051] Accordingly, in step S220 the best matching template is determined by selecting the template having the lowest calculated correlation factor.

[0052] Optionally, the correlation measure calculated using either equation (1) or equation (2) may be normalised by dividing it by the sum of the squares. In this case, equation (1) becomes equation (3) as shown below;

$$C_i = \frac{\sum_{j=1:N} crk_j \times temp_{ij}}{\sum_{j=1:N} (crk_j^2 + temp_{ij}^2)} \quad (3)$$

and equation (2) becomes equation (4) as shown below;

$$C_i = \frac{\sum_{j=1:N} (crk_j - temp_{ij})^2}{\sum_{j=1:N} (crk_j^2 + temp_{ij}^2)} \quad (4)$$

[0053] In yet another embodiment of the present invention, the correlation function may be based purely on the magnitude of the approximately sinusoidal crank tooth time pattern, calculated by subtracting the minimum crank tooth time in one combustion cycle from the maximum tooth time in the cycle as shown in equation (5) below;

$$C_i = \sum_{j=1:N} [\max(crk_j) - \min(crk_j)] - [\max(temp_j) - \min(temp_j)] \quad (5)$$

[0054] In the case that the correlation measure is calculated using equation (5), in step S220, the best matching template is determined by selecting the template having the lowest calculated correlation measure.

[0055] In order to minimise variation from engine to engine due to differences in cylinder pressurisation (e.g. due to piston ring sealing) or crank tooth size differences (e.g. due to machining tolerances), a zero torque datum may be subtracted from each set of crank tooth times.

[0056] The zero torque datum may be calculated as follows;

- a) Run in engine in zero load state (detectable from gearbox or clutch state)
- b) Record zero load crank tooth times for each cylinder crk_0
- c) Subtract zero load tooth time from the measured crank tooth time $clean_crk_j = crk_j - crk_0$

[0057] The correlation calculation would then use one of the above correlation measures, equations (1) to (5), with the template also scaled by subtraction of an idealised zero torque crank time, $clean_temp_i = temp_j - temp_0$.

[0058] In addition to or instead of using the estimated torque output to perform fault diagnosis, in an alternative embodiment of the present invention, fault diagnosis may be performed utilising templates which correspond to specific engine faults. The process for diagnosing an engine fault using template comparison is similar to the processes shown in Figures 4 and 6 and will be described in more detail below.

[0059] In a compression-ignition combustion engine, such as a diesel fuel engine system, faults may arise from variations in the fuel injection quantity, cylinder pressure or the injection timing. In particular, a misfire can be caused by either a total failure to inject fuel or a loss of cylinder pressure. Faults of this nature are associated with a deceleration in the rotational speed of the engine. Additionally, there are failure modes that cause an increase in the engine's rotational speed, such as a fuel injector needle being stuck open.

[0060] In the template creation generating process of Figure 4, the test engine may be operated so as to simulate a fault, such as one of those described above. Accordingly, engine speed measurements may be recorded in step S120,

over a predetermined range of rotation of the crankshaft, which are characteristic of the simulated engine fault. The engine speed measurements may then be stored in the storage means 38 in association with fault identification information thereby defining a template.

[0061] As described previously, templates may be created corresponding to a range of average engine speeds and a range of torque outputs. The generated templates may subsequently be transferred to the memory 58 of the ECU 56 of a vehicle engine for fault diagnosis.

[0062] Referring again to Figure 6, fault diagnosis is performed by carrying out steps S200, S210 and S220 as described previously. In step S200, engine speed measurements are recorded during running of the engine 52. In step 210, the measured engine data is compared to the templates stored in the memory 58, which include the fault specific templates. In step S220, the template with the highest calculated correlation factor is selected. In the event that a fault specific template has the highest correlation factor, the ECU 56 diagnoses that the engine is suffering from a fault corresponding to the fault identification information which is associated with the best matching template.

[0063] It will be understood that the embodiments described above are given by way of example only and are not intended to limit the invention, the scope of which is defined in the appended claims. It will also be understood that the embodiments described may be used individually or in combination.

[0064] It is noted that the term "crank teeth" is taken to cover both projections from the crank wheel as shown in Figure 1 or alternatively drilled holes in the crank wheel.

Claims

1. A monitoring unit for determining the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the unit comprising:

inputs for receiving first data related to engine rotation;

storage means (58) for storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition; and

processing means (56) configured: i) to compare said received first data to said second data in order to determine a best matching template, and ii) to determine the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

2. A monitoring unit according to claim 1, wherein said one or more engine parameters includes an engine torque output value, and determining the operational condition of the engine comprises determining the torque output of the engine in dependence on the engine torque output value associated with said best matching template.

3. A monitoring unit according to claim 1 or 2, wherein said one or more engine parameters includes an average engine speed.

4. A monitoring unit according to any one of claims 1, 2 and 3, wherein said one or more engine parameters includes fault identification information, and said processing means (56) is arranged to determine the operational condition of the engine by determining if an engine fault has occurred in dependence on fault identification information associated with said best matching template.

5. A monitoring unit according to claim 5, wherein said fault identification information comprises one of:

an indication of an engine cylinder misfire; and

an indication of a fuel injector needle stuck open condition.

6. A monitoring unit according to any preceding claim, wherein the first and second data related to engine rotation comprises data relating to the rotation of a crank wheel (2) within the engine (52).

7. A monitoring unit according to claim 6, wherein the crank wheel (2) comprises a group (6; 8; 10) of regularly spaced crank teeth (4) associated with each cylinder within the engine (52) and the processing means (56) is arranged to monitor the time taken for a given crank tooth to move past a crank tooth sensor (18) and to subsequently determine the speed of the crank wheel (2).

8. A monitoring unit according to claim 7, wherein said first and second data related to engine rotation comprises a plurality of crank tooth times.
9. A monitoring unit according to claim 8, wherein said first and second data related to engine rotation comprises crank tooth times for one group (6; 8; 10) of crank teeth associated with a particular engine cylinder.
10. A monitoring unit according to claim 8, wherein said first and second data related to engine rotation comprises crank tooth times for each crank tooth (4) on the crank wheel (2).
11. A monitoring unit according to any one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} crk_j \times temp_{ij}$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template having the highest calculated correlation factor.

12. A monitoring unit according to any one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} (crk_j - temp_{ij})^2$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template having the lowest calculated correlation factor.

13. A monitoring unit according to claim 11 or claim 12, wherein said processing means (56) is arranged to calculate a normalised correlation factor for each of said plurality of templates by dividing said correlation factor by the following expression;

$$\sum_{j=1:N} (crk_j^2 + temp_{ij}^2)$$

14. A monitoring unit according to one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} [\max(crk_j) - \min(crk_j)] - [\max(temp_j) - \min(temp_j)],$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template

having the lowest calculated correlation factor.

- 5 15. A method of monitoring the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the method comprising:

receiving first data related to engine rotation (S200);
 storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition;
 10 comparing said first data to said second data (S210);
 determining a best matching template in dependence on the result of said comparing step (S220); and
 determining the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

- 15 16. A data carrier comprising a computer program arranged to configure a torque estimating unit or an engine control unit to implement the method according to claim 15.

- 20 17. A method of generating templates for use in an engine monitoring unit, the method comprising:

operating an engine in accordance with a particular operational condition;
 receiving data related to engine rotation; and
 storing said data related to engine rotation in association with one or more engine parameters associated with said operational condition.

- 25 18. A method according to claim 17, wherein said one or more engine parameters comprises an engine torque output value.

- 30 19. A system for generating templates for use in an engine monitoring unit, the system comprising:

an engine (32) operable in accordance with a particular operational condition;
 an engine speed sensor (18) for outputting data related to engine rotation;
 storage means (38); and
 processing means (36) arranged to receive said data related to engine rotation and to store said data in said storage means (38) in association with one or more engine parameters associated with said operational condition.

- 35 20. A system according to claim 19, comprising an engine torque output sensor (34), wherein one or more engine parameters comprises an engine torque output value.

Amended claims in accordance with Rule 137(2) EPC.

- 45 1. A monitoring unit for determining the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the unit comprising:

inputs for receiving first data related to engine rotation;
 storage means (58) for storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition; and
 50 processing means (56) configured: i) to compare said received first data to said second data in order to determine a best matching template selected from said plurality of templates, and ii) to determine the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

- 55 2. A monitoring unit according to claim 1, wherein said one or more engine parameters includes an engine torque output value, and determining the operational condition of the engine comprises determining the torque output of the engine in dependence on the engine torque output value associated with said best matching template.

3. A monitoring unit according to claim 1 or 2, wherein said one or more engine parameters includes an average engine speed.
4. A monitoring unit according to any one of claims 1, 2 and 3, wherein said one or more engine parameters includes fault identification information, and said processing means (56) is arranged to determine the operational condition of the engine by determining if an engine fault has occurred in dependence on fault identification information associated with said best matching template.
5. A monitoring unit according to claim 5, wherein said fault identification information comprises one of:
 - an indication of an engine cylinder misfire; and
 - an indication of a fuel injector needle stuck open condition.
6. A monitoring unit according to any preceding claim, wherein the first and second data related to engine rotation comprises data relating to the rotation of a crank wheel (2) within the engine (52).
7. A monitoring unit according to claim 6, wherein the crank wheel (2) comprises a group (6; 8; 10) of regularly spaced crank teeth (4) associated with each cylinder within the engine (52) and the processing means (56) is arranged to monitor the time taken for a given crank tooth to move past a crank tooth sensor (18) and to subsequently determine the speed of the crank wheel (2).
8. A monitoring unit according to claim 7, wherein said first and second data related to engine rotation comprises a plurality of crank tooth times.
9. A monitoring unit according to claim 8, wherein said first and second data related to engine rotation comprises crank tooth times for one group (6; 8; 10) of crank teeth associated with a particular engine cylinder.
10. A monitoring unit according to claim 8, wherein said first and second data related to engine rotation comprises crank tooth times for each crank tooth (4) on the crank wheel (2).
11. A monitoring unit according to any one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} crk_j \times temp_{ij}$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template having the highest calculated correlation factor.

12. A monitoring unit according to any one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} (crk_j - temp_{ij})^2$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template having the lowest calculated correlation factor.

13. A monitoring unit according to claim 11 or claim 12, wherein said processing means (56) is arranged to calculate a normalised correlation factor for each of said plurality of templates by dividing said correlation factor by the following expression;

$$\sum_{j=1:N} (crk_j^2 + temp_{ij}^2)$$

14. A monitoring unit according to one of claims 8, 9 and 10, wherein said processing means (56) is arranged to compare said first and second data by calculating a correlation factor for each of said plurality of templates using the following equation;

$$C_i = \sum_{j=1:N} [\max(crk_j) - \min(crk_j)] - [\max(temp_j) - \min(temp_j)]_i$$

where j = a crank tooth index, i = a template number index, crk = crank tooth time received at the input, and $temp$ = a crank tooth time stored in a particular template; and wherein the processing means (56) is arranged to determine said best matching template by selecting the template having the lowest calculated correlation factor.

15. A method of monitoring the operational condition of an engine, the engine comprising a plurality of cylinders, each cylinder comprising a combustion chamber into which fuel is injected by an associated fuel injector, the method comprising:

receiving first data related to engine rotation (S200);

storing a plurality of templates, each template comprising second data related to engine rotation, said second data being characteristic of a particular operational condition, and one or more engine parameters associated with said operational condition;

comparing said first data to said second data (S210);

determining a best matching template in dependence on the result of said comparing step (S220), said best matching template being selected from said plurality of templates; and

determining the operational condition of the engine in dependence on said one or more engine parameters associated with said best matching template.

16. A data carrier comprising a computer program arranged to configure a torque estimating unit or an engine control unit to implement the method according to claim 15.

17. A method of generating templates for use in an engine monitoring unit, the method comprising;

operating an engine in accordance with a particular operational condition;

receiving data related to engine rotation; and

storing said data related to engine rotation in association with one or more engine parameters associated with said operational condition, thereby defining a template.

18. A method according to claim 17, wherein said one or more engine parameters comprises an engine torque output value.

19. A system for generating templates for use in an engine monitoring unit, the system comprising:

an engine (32) operable in accordance with a particular operational condition;

an engine speed sensor (18) for outputting data related to engine rotation;

storage means (38); and

processing means (36) arranged to receive said data related to engine rotation and to store said data in said storage means (38) in association with one or more engine parameters associated with said operational condition, thereby defining a template.

- 20.** A system according to claim 19, comprising an engine torque output sensor (34), wherein one or more engine parameters comprises an engine torque output value.

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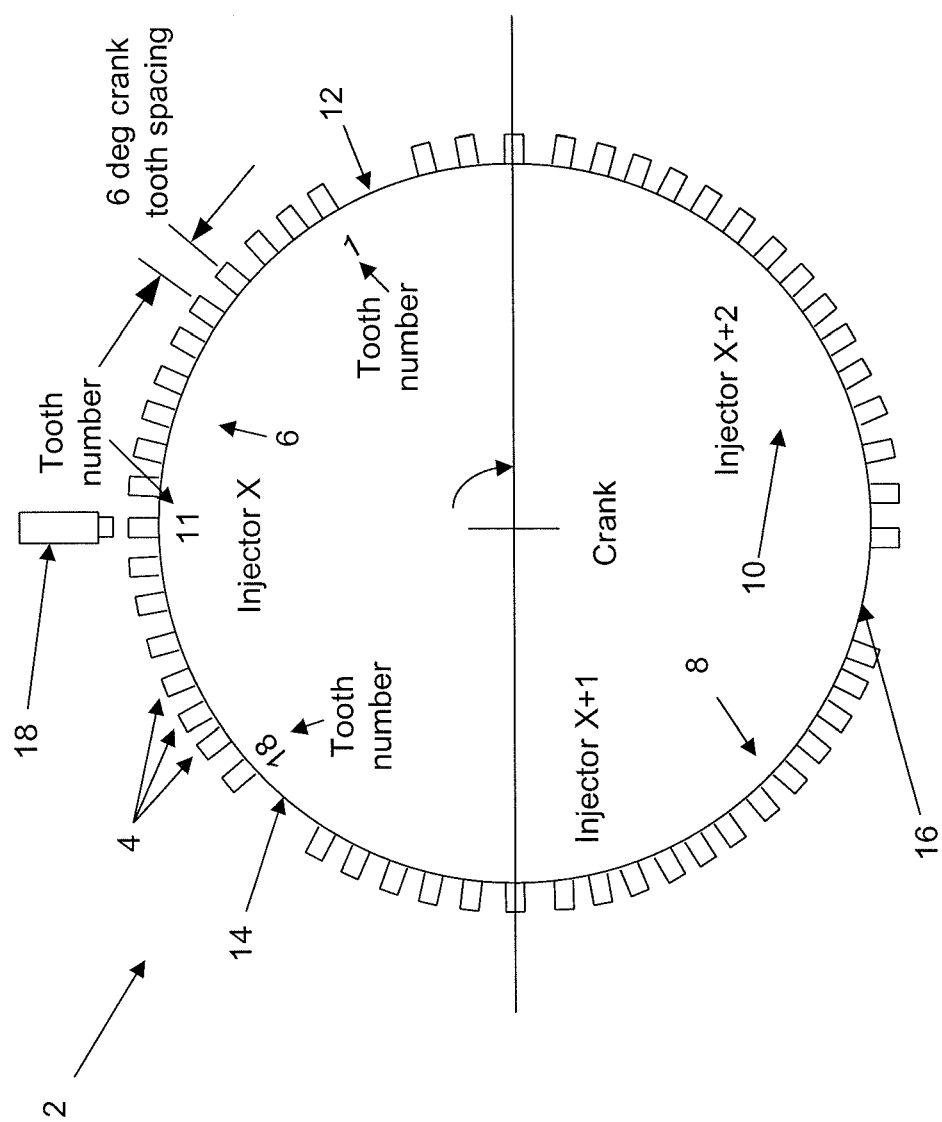


Fig. 1

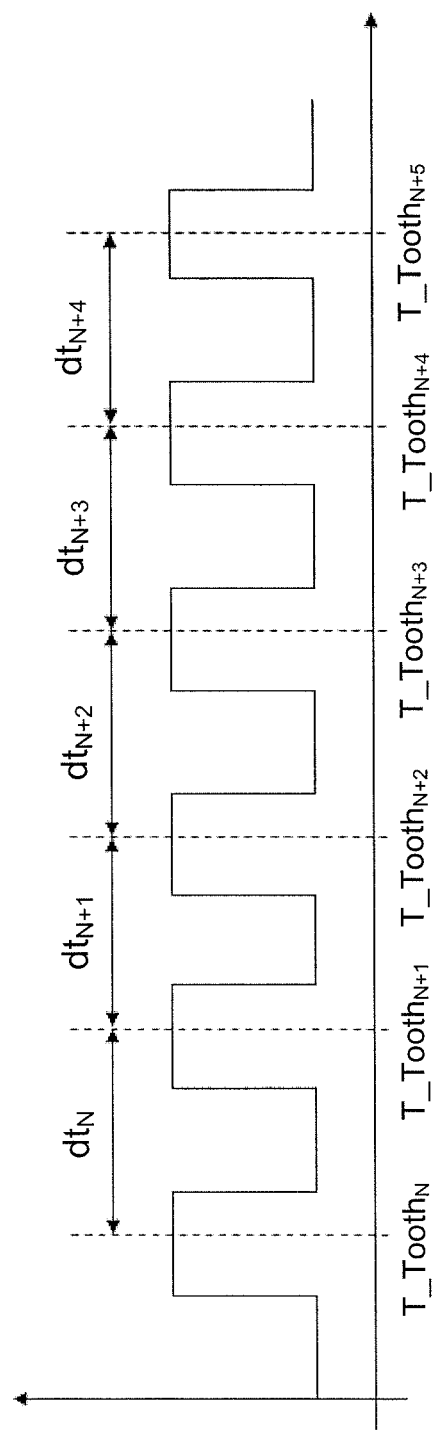


Fig. 2

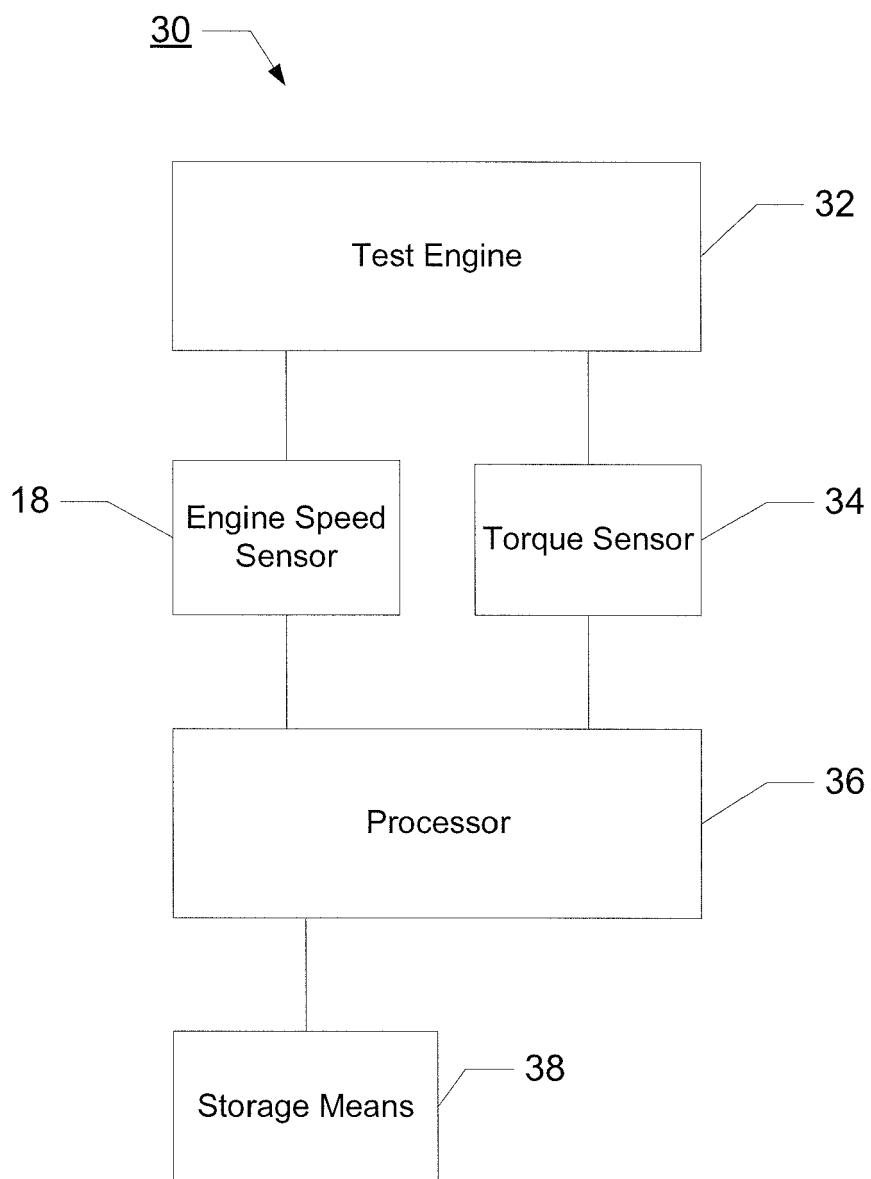


Fig. 3

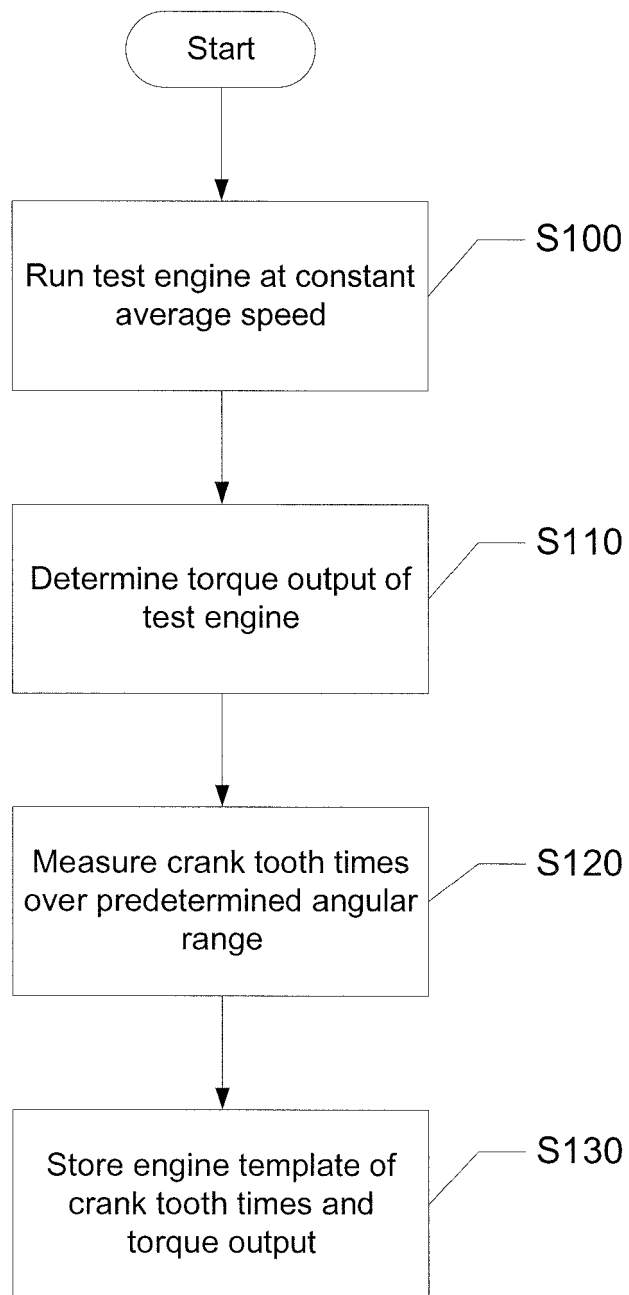


Fig. 4

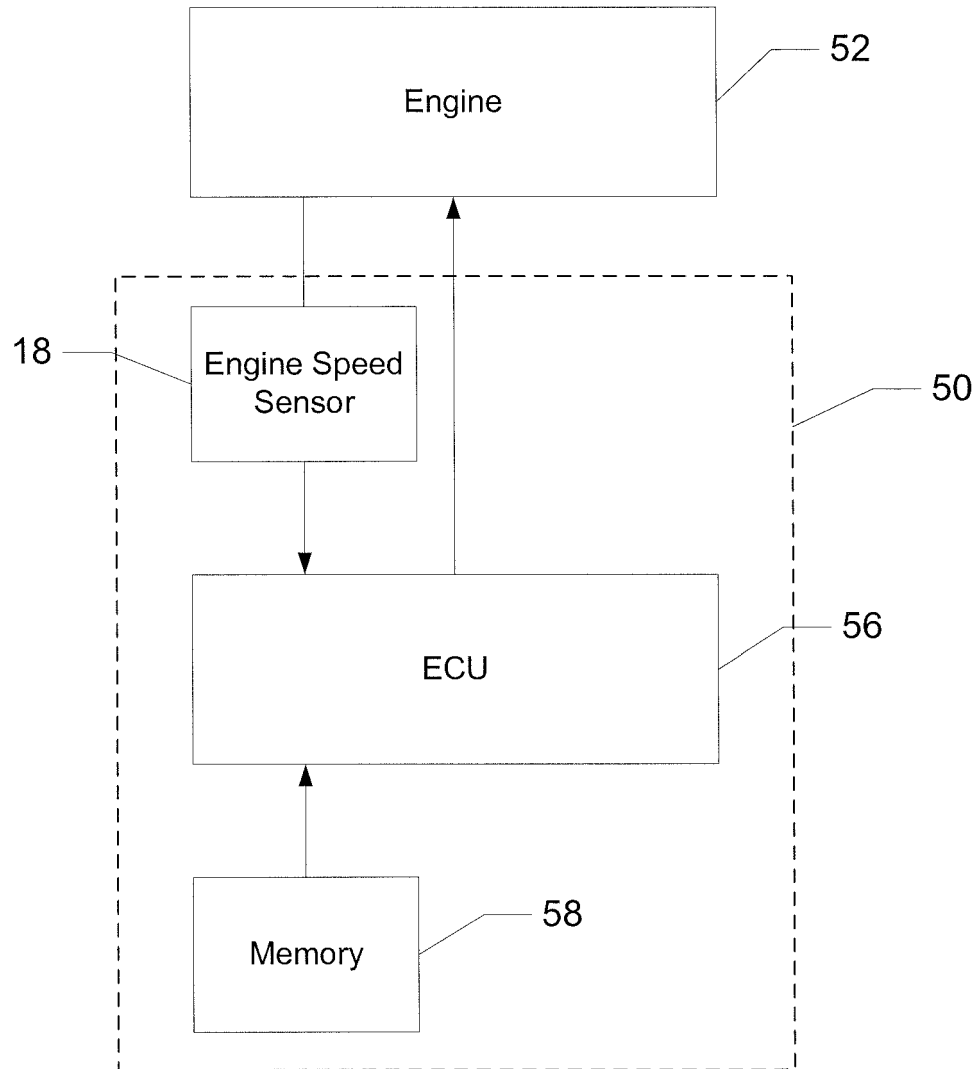


Fig. 5

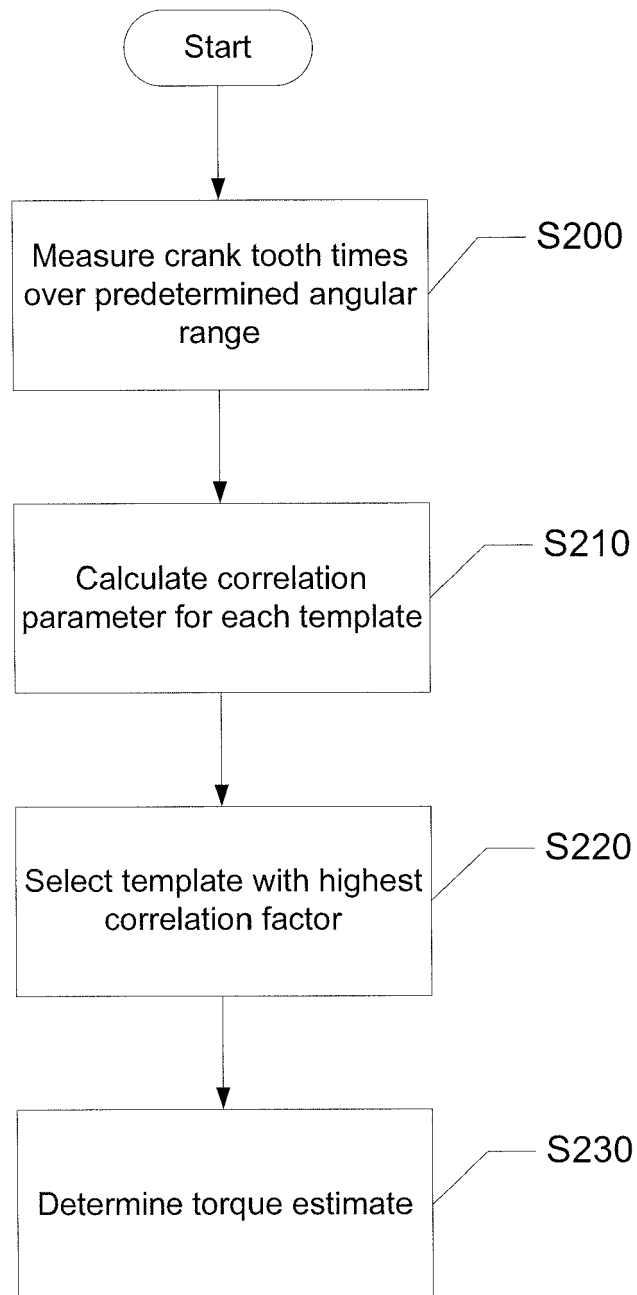


Fig. 6



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 08 07 5042

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 199 28 664 A1 (BOSCH GMBH ROBERT [DE]) 28 December 2000 (2000-12-28) * abstract * * figure 1 * * column 1, line 61 - column 3, line 53 * -----	1-10, 15-20	INV. F02D41/14 F02D41/24
A	DE 102 32 806 A1 (BAYERISCHE MOTOREN WERKE AG [DE]) 5 February 2004 (2004-02-05) * paragraphs [0005] - [0011] * -----		
A	DE 102 14 833 A1 (VOLKSWAGEN AG [DE]) 16 October 2003 (2003-10-16) * paragraphs [0006] - [0012] * -----		
			TECHNICAL FIELDS SEARCHED (IPC)
			F02D G01L G01M
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 11 July 2008	Examiner Parmentier, Hélène
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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EP 08 07 5042

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11-07-2008

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